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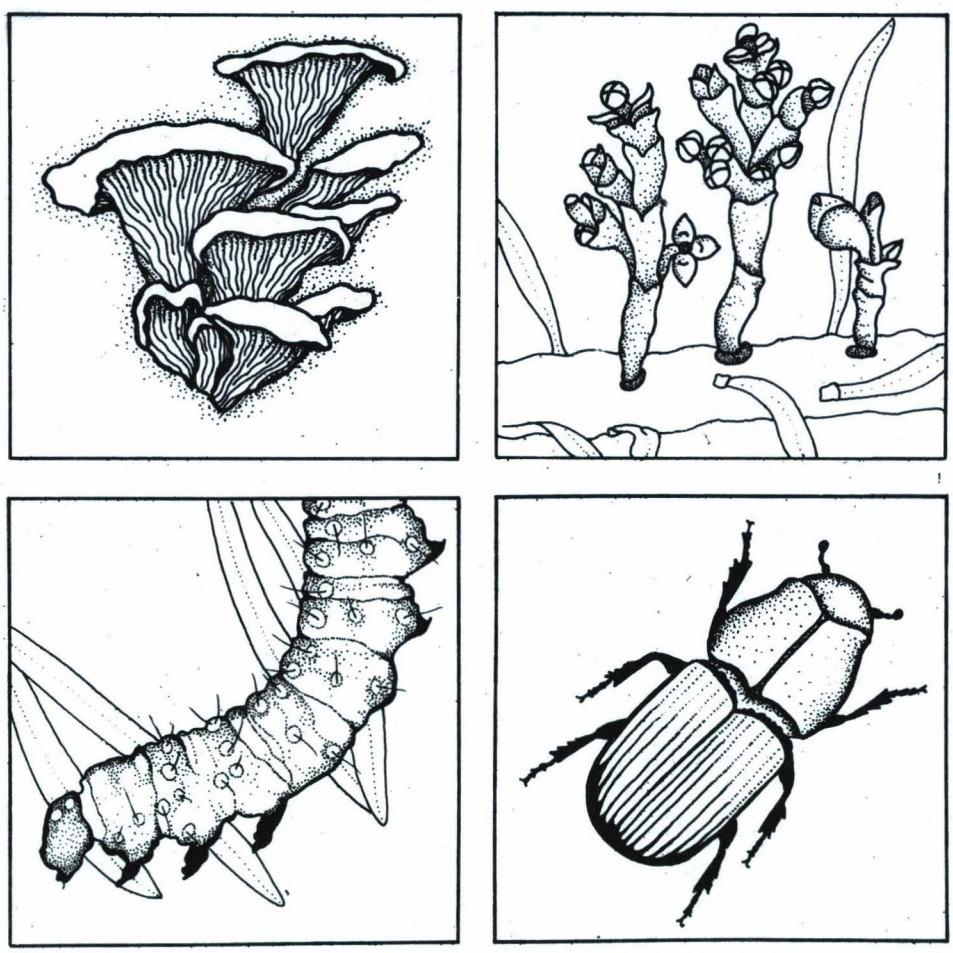
Evaluation of Multistage Sampling Techniques to Measure Lodgepole Pine Mortality caused by Mountain Pine Beetle in Montana, 1979

by D. D. Bennett, W. E. Bousfield, M. D. McGregor and K. E. Gibson



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EVALUATION OF MULTISTAGE SAMPLING TECHNIQUES TO MEASURE LODGEPOLE PINE MORTALITY CAUSED BY MOUNTAIN PINE BEETLE IN MONTANA, 1979

By

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ABSTRACT

A pilot survey was conducted to evaluate the effectiveness of using multistage sampling techniques to measure annual and cumulative mortality on a State-wide basis with acceptable statistical reliability, timeliness, and cost.

Within the State of Montana, aerial surveys showed about 986,000 acres of lodgepole pine infested with mountain pine beetle. This area was stratified into three intensity classes. Initial stratification, from 1979 aerial sketchmap surveys, was followed by large-scale (1:6000) aerial photography (on a sample basis), photo interpretation, and ground truth measurements. Photo plots were selected by a systematic random process for each stratum. Ground truth plots were chosen by probability proportional to size (pps).

Estimates of 1978 attacked lodgepole pine (faders) were 11.6 million trees, representing a volume of 161.4 million cubic feet. Relative sampling errors were 9.8 and 16.5 percent for numbers of faders and volume, respectively. The total number of standing dead was 33.4 million trees, with a volume of 517 million cubic feet. The survey required 257 man-hours at a cost of $43,500.

INTRODUCTION

Since 1969, mountain pine beetle 1/ epidemics have caused extensive mortality to lodgepole pine stands throughout the State of Montana. By 1979, mortality occurred on more than 986,000 acres and claimed a previously undetermined number of trees and volume. To make proper management decisions, local Forest and National program managers requested a timely, accurate inventory to measure magnitude of tree mortality (Ciesla and Klein 1978).

Multistage survey systems designed to provide current and statistically reliable mortality information have recently been developed and tested on localized infestations in Idaho, Colorado, and Montana (Klein et al. 1979; Hostetler and Young 1979; Bennett and Bousfield 1979). The primary objective of this pilot test was to implement these multistage sampling methods to measure annual mortality, on a State-wide basis, with similar statistical reliability, timeliness, and comparable cost. Other objectives were to measure cumulative mortality, including 1979 attacks, and compare basal area of dead lodgepole pine to the residual green stand.

1/ Dendroctonus ponderosae Hopk.

SITE DESCRIPTION

The survey area covered approximately 986,000 acres of infested lodgepole pine type on portions of nine National Forests and two National Parks, including State and private ownerships, throughout western Montana (figure 1). For convenience, description of this area is grouped as follows:

Beaverhead and Gallatin National Forests - Beetle activity over these two Forests and intermixed private lands is regarded as one infestation. About 119,360 acres are infested on the Beaverhead NF and 417,800 acres on the Gallatin NF. Infestation extends from the Idaho-Montana border to the north end of the Bridger Mountains.

Bitterroot National Forest - Approximately 830 acres are infested in Sheephead Creek drainage near the Idaho-Montana border. This outbreak was detected in 1979, and has the potential to increase throughout surrounding susceptible lodgepole pine stands.

Deerlodge National Forest - Beetle activity is limited to four small outbreak centers. Two are located southeast of Butte (Toll Mountain/Pigeon Creek; and Homestake Creek/Whiskey Gulch); one northeast of Butte, near Elder Creek campground; and the fourth is in Rock Creek drainage west of Philipsburg. All four are recent (1978) outbreaks, and consist of only 200 acres combined.

Flathead National Forest/Glacier National Park - This infestation, covering nearly 340,000 acres, is located from the United States-Canadian border south throughout Glacier National Park and the Glacier View Ranger District. Several lesser outbreaks are located at Hungry Horse Dam; Spotted Bear Ranger Station south to Meadow Creek; Stillwater River from Bull Lake to lower Stillwater Lake; south of Werner Peak; west of Tally Lake; Columbia Falls; and Ashley Lake south to Moore Springs.

Helena National Forest - About 770 acres are infested. The largest infestation is south of Deep Creek campground, with smaller, widely scattered outbreaks in the Elkhorn and Belt Mountains.

Kootenai National Forest - Several separate infestations occur on 66,000 acres of National Forest. The largest is located throughout the northern half of the Yaak River drainage. Additional outbreaks occur in the Gold, Pinkham, and Sunday Creek drainages; and south from Wolf Creek to the Lolo National Forest boundary.

Lewis and Clark National Forest - Infested lodgepole pine is limited to 125 acres in the Castle Mountains between Boulder Creek and Warm Springs Creek.

Lolo National Forest - Most of the 12,000 infested acres occur on mixed National Forest and State and private lands in the Thompson River drainage from McGregor Lake southwest to Deerhorn Mountain. Other isolated infestations are located at Buffalo Bill and Gold Creek drainages; Clearwater, Colt, Rainy, and Placid Lakes; and the West Fork of Clearwater River drainage.

Yellowstone National Park - Only that portion of Yellowstone National Park that is in Montana was surveyed. Approximately 34,000 acres are infested from Divide Lake south to the Idaho State line.

The total survey covered a wide range of terrain, habitat types, and stand conditions. Lodgepole pine was the predominant tree species, with lesser amounts of Engelmann spruce, Douglas-fir, western larch, subalpine fir, whitebark, limber, and western white pines, grand fir, western redcedar, western and mountain hemlock, and aspen.

The survey design was the same as those used in similar surveys conducted by Regions 1 and 2 (Bennett and Bousfield 1979; Hostetler and

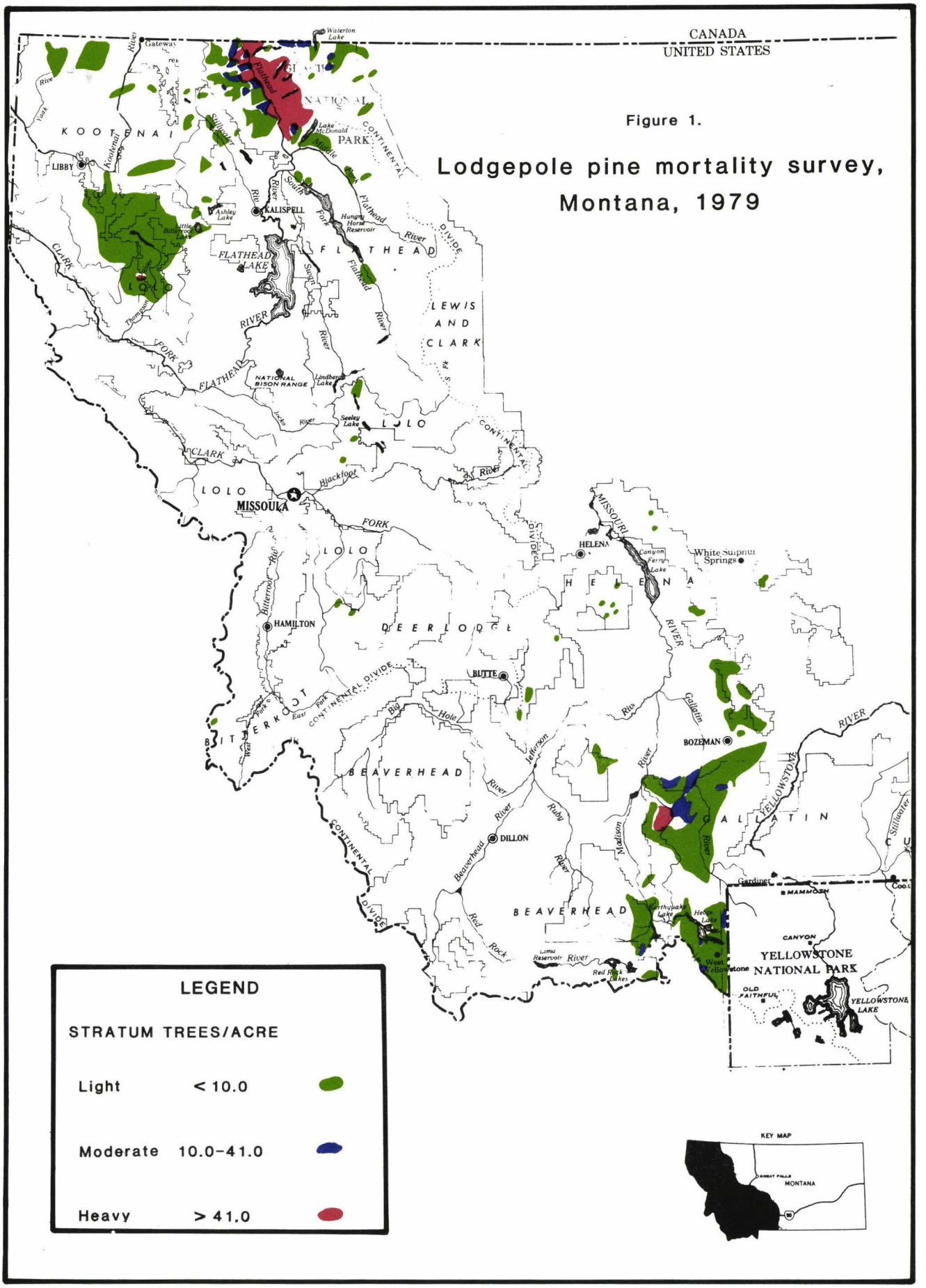

Figure 1.

Lodgepole pine mortality survey, Montana, 1979

Young 1979). It consisted of aerial sketchmapping, stratification of the infestation into three intensity classes, large-scale aerial photography, photo interpretation, and ground truth measurements (Klein et al. 1979).

AERIAL SKETCHMAPPING

All infestations were aerially sketchmapped between July 16 and August 16, 1979. Approximately 140 flight hours were required at a cost of $8,800. Other insect and disease damage was mapped concurrently over much of the area to eliminate duplication of annual aerial detection surveys.

STRATIFICATION

Stratification of the sketchmapped area resulted in 1,029 polygons of varying size. After reviewing faded tree density distributions, the strata limits were set at (1) less than 10.0 trees per acre; (2) 10.0-41.0 trees per acre; and (3) greater than 41.0 trees per acre (table 1).

Table 1.--Stratification by intensity class and allocation of photo plots and ground plots per stratum

	Aerial sketchmapping				No. of	No. of
Stratum	Est. No. of faders	Acres	Trees per acre	No. of polygons	photo plots	ground plots
1	1,706,167	666,602	<10	945	174	18
2	1,829,890	95,288	10.0-41.0	70	87	19
3	14,360,000	224,022	>41.0	14	81	20
TOTAL	17,896,057	985,912		1,029	342	57

AERIAL PHOTOGRAPHY

Aerial photography was taken by Forest Insect and Disease Management personnel from Region 5 using a Zeiss RMK 21/23 aerial camera mounted in an Aerocommander 500B aircraft. Ektachrome SO-397 film was used to take 9- by 9-inch stereo pairs at each of 342 designated plots. The approximate scale was 1:6000.

In previous surveys, photo plots were selected along north-south flight lines spaced 1 mile apart. This method was impractical for our survey because of the scattered nature and great distances between infestations. We therefore established flight lines and photo plot intervals using the following grid method reported by the Southeast Area Division of Forest Pest Control (1970):

$$I = \sqrt{\frac{A}{N}}$$

Where: A = total area to be surveyed in square miles or square meters

N = number of photo plots

I = flight line interval and photo plot interval in miles or meters

Using this method flight lines and photo plot intervals were established in each stratum as follows:

Stratum	Interval	No. of Photo Plots
1	2.5 miles	174
2	1.25 miles	87
3	2.0 miles	81

All photo plots were located on standard Forest maps (1:126,720), then transferred to high-altitude photo mosaics (1:120,000). These mosaics were used by the aerial photographers for orientation and plot location.

PHOTO INTERPRETATION

Photo plots were interpreted by three experienced photo interpreters using Old Delft scanning stereoscopes. A 40-acre template (1:6000 scale) was placed on the center of effective stereo area of each photo pair. Each template was subdivided into sixteen 2.5-acre subplots. New faders (1978 attacks) were counted and recorded on each 2.5-acre subplot. Photos were interpreted September 2-20, 1979.

GROUND TRUTH ACQUISITION

Ten photo plots were selected by pps from each stratum. Two 2.5-acre subplots were then selected by pps from each of these 10 plots, making a total of sixty 2.5-acre ground plots. Timber harvesting (clearcutting) prevented ground truth acquisition on three 2.5-acre ground truth plots, leaving 57 plots surveyed.

Ground truth plots were located and surveyed between September 16 and October 15, 1979, by the method detailed in previous surveys (Bennett and Bousfield 1979; Hostetler and Young 1979), with two exceptions:

1. Tree heights were not measured during the 100 percent cruise. Volume was calculated from regression estimators developed from local forest inventory plots which predict heights for given measured diameters.

2. Previous surveys recorded only dead trees in diameter classes 5 inches and greater. We included all dead trees $\geq$3 inches diameter at breast height (d.b.h.) because these trees constituted a significant amount of mortality in some areas.

DATA ANALYSIS

Data analysis consisted of (1) determining the relationship between photo interpreter counts of faders and counts of faders made on the ground; (2) estimating the number and volume of

lodgepole pine killed during 1978, 1979, and total standing dead, with an associated sampling error; (3) comparing basal area of dead lodgepole pine with that of the residual green stand; and (4) determining the cost of the survey in man-days and dollars.

Formulae used to determine the number of trees and volume killed in 1978 and the relationship between photo and ground counts were the same as those used by Bennett and Bousfield (1979). Variable plot data were analyzed by the computer program INDIDS (Bousfield 1979) to calculate and display trees and volume per acre by damage class for all species. These figures were then multiplied by 2.5 acres per plot and substituted into the same formulae used to derive the 1978 mortality estimates. This generated estimates for the number and volume of total standing dead.

RESULTS

Correlations between photo and ground counts were good for strata 1 and 2 with coefficient of determination (R^2) values of 0.94 and 0.87, respectively. However, the R^2 value of stratum 3 was 0.35, and that of the combined data was 0.70. Linear regression slope (b) estimates indicated the photo counts underestimated ground counts in stratum 1. Strata 2, 3, and combined data show photo counts overestimated ground counts. The values were (1) b = 1.31; (2) b = 0.87; (3) b = 0.37; and (combined) b = 0.68.

Results indicate that approximately 11.6 million lodgepole pine containing a volume of 161.4 million cubic feet were killed by mountain pine beetle throughout the State of Montana in 1978 (table 2). Relative sampling errors were 9.8 and 16.5 percent for faders and volume respectively.

Table 2.--Estimates of numbers of trees and volume of lodgepole pine killed by mountain pine beetle throughout Montana in 1978 (determined from 100 percent cruise data)

Strata	Acres	No. of faders	Standard error	Volume per tree	Total volume	Standard error
				cu. ft.	(M cu. ft.)	
1	666,602	4,237,710 (17.2)*	727,083	18.7	79,280 (22.3)*	17,717
2	95,288	1,358,447 (17.9)*	242,256	12.1	16,376 (18.3)*	3,001
3	224,022	6,031,202 (13.6)*	840,640	10.9	65,752 (29.8)*	19,575
TOTAL	985,912	11,627,359 (9.8)*	1,137,633	13.9	161,408 (16.5)*	26,572

* Percent standard error

By substituting the expanded variable plot data into the estimator formulae, we derived the following estimates:

1. The number of trees attacked in 1979 was 9.9 million (29.9 percent standard error), containing a volume of 167.1 million cubic feet (38.9 percent standard error) (table 3).

Table 3.--Estimates of numbers of trees and volume of lodgepole pine killed by mountain pine beetle throughout Montana in 1979 (determined from variable plot data)

Strata	Acres	No. of new attacks	Standard error	Volume per tree	Total volume	Standard error
				cu. ft.	(M cu. ft.)	
1	666,602	5,901,632 (41.9)*	2,131,748	24.0	141,386 (44.9)*	63,450
2	95,288	726,451 (41.1)*	298,219	14.8	10,784 (67.5)*	7,283
3	224,022	3,364,823 (61.7)*	2,076,739	4.4**	14,930 (80.7)*	12,053
TOTAL	985,912	9,992,906 (29.9)*	2,991,008	16.7	167,099 (38.9)*	64,994

* Percent standard error

** Many attacked trees <5 inches d.b.h.

2. The number of trees attacked in 1978 was 10.2 million (11.5 percent standard error), with a volume of 122.7 million cubic feet (18.7 percent standard error) (table 4).

Table 4.--Estimates of numbers of trees and volume of lodgepole pine killed by mountain pine beetle throughout Montana in 1978 (determined from variable plot data)

Strata	Acres	No. of faders	Standard error	Volume per tree	Total volume	Standard error
				cu. ft.	(M cu. ft.)	
1	666,602	2,050,071 (17.0)*	348,497	15.2	31,117 (13.4)*	4,155
2	95,288	1,258,627 (34.2)*	430,717	12.5	15,747 (28.6)*	4,507
3	224,022	6,865,561 (15.0)*	1,029,922	11.1	75,869 (29.1)*	22,055
TOTAL	985,912	10,174,259 (11.5)*	1,169,490	12.1	122,733 (18.7)*	22,891

* Percent standard error

3. Total dead lodgepole was 33.4 million (27.9 percent standard error), with a volume of 517.0 million cubic feet (36.5 percent standard error) (table 5).

Table 5.--Estimates of numbers of trees and volume of the total standing dead lodgepole pine killed by mountain pine beetle, in Montana, through 1979 (determined from variable plot data)

Strata	Acres	No. of standing dead	Standard error	Volume per tree	Total volume	Standard error
				cu. ft.	(M cu. ft.)	
1	666,602	17,604,638 (50.3)*	8,861,117	19.1	335,567 (53.9)*	180,761
2	95,288	2,539,588 (20.0)*	506,849	13.2	33,507 (27.7)*	9,290
3	224,022	13,234,078 (21.2)*	2,807,487	11.2	147,950 (35.6)*	52,726
TOTAL	985,912	33,378,304 (27.9)*	9,309,043	15.5	517,024 (36.5)*	188,523

* Percent standard error

Lodgepole pine made up 67.8 percent of the total basal area for all strata combined (table 6). Of the lodgepole component, 60.3 percent has been killed by mountain pine beetle. Other host species including whitebark, limber, and western white pine, and Engelmann spruce have been killed in minimal quantities (table 6). Several unsuccessfully attacked western larch were also observed in areas of very extensive mortality.

Table 6.--Estimates of percent total basal area by stratum and species composition in 1979 survey of Montana

Stratum	Lodgepole pine		Whitebark/ Limber pine		White pine		Spruce		Nonhost Species (live)				TOTAL
	live	dead	live	dead	live	dead	live	dead	Douglas-fir	Subalpine fir	Larch	Others*	
1	31.4	31.2	0.2	0.0	1.1	0.2	9.7	0.2	8.8	2.0	7.3	7.9	100.0
2	38.8	32.4	.6	2.1	.0	.0	10.9	.0	5.3	7.8	2.1	.0	100.0
3	11.0	58.2	.0	.0	.4	.2	6.3	.1	8.8	2.5	12.5	.0	100.0
Weighted mean	26.9	40.9	.3	.7	.5	.1	8.9	.1	7.6	4.2	7.3	2.5	100.0

* Other species include: grand fir, western redcedar, western/mountain hemlock, aspen

Approximately 257 man-hours were required to complete this survey at a cost of $43,500 (appendix A). This workload, shared by Regions 1 and 5, and the Methods Application Group, involved assistance from 20 individuals.

DISCUSSION AND RECOMMENDATIONS

This survey demonstrated that mortality of lodgepole pine can be measured on a State-wide basis with statistical reliability, timeliness, and at a reasonable cost using recently developed multistage sampling survey methods. Estimates of current faders and volume loss were within the National requirement of ±20 percent standard error. The survey also provided estimates of the number and volume of new attacks and total standing dead. We recognized that some areas of new attacks as well as areas of old mortality were omitted; and that the variability of new attack and total standing dead estimates were high, increasing the standard errors. However, these estimates may be more meaningful than estimates lacking statistical parameters.

In many areas surveyed, particularly in stratum 3, a significant proportion of the faders were in the 3- and 4-inch d.b.h. size class. We therefore included these smaller trees in our survey, even though their volume was negligible.

Although these State-wide mortality estimates satisfy National requirements for statistically reliable, timely information, such broad estimates are of limited benefit to local land managers who need mortality information specific to their management units. A possible means of providing mortality estimates at both levels may be to partition and survey mortality by separate infestations or Forests. Information from each area could then be combined into a State-wide mortality estimate.

To reduce cost and increase efficiency of future surveys, we recommend mortality estimates be limited to areas where timber management and harvesting are options. Only acres infested would be reported for areas classified as Wilderness and National Parks.

Because the sampling error was considerably lower than the required standard of ±20 percent established by the Washington Office, we recommend the minimum sample size required to maintain a ±20 percent standard error be determined in order to reduce sampling during future surveys.

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Appendix A. Timetable and estimated costs of the survey, Montana 1979

Activity	Dates	Man-days	Cost
Aerial Sketchmapping			
a. Sketchmapping	7/16-8/16, 1979	18	$8,000
b. Area digitizing	7/30-8/1, 8/17, 1979	5	270
c. Stratification	8/2, 1979	3	160
Aerial Photography			
a. Planning; plot and flight line determination	8/3-5, 1979	7	375
b. Aerial photography	8/8-12, 9/5-6, 1979	24	7,250
c. Processed film received	8/31, 1979		
d. Photo and map indexing	8/31, 9/1, 1979	3.5	190
Photo Interpretation	9/2-20, 1979	27	1,900
Ground Plot Selection	9/15-24	5	270
Ground Truth Acquisition	9/16-10/15	142	7,575 (salaries) 4,970 (travel) 8,655 (helicopter) 1,900 (vehicles)
Data Compution and Analysis	11/28, 1979-1/25, 1980	16	850
Report Writing	2/4-22, 1980	6	320
Total		256.5	$43,485